

The Modification of Human Society by Natural Systems: Discontinuities Caused by the Exploitation of Endemic Species and the Introduction of Exotics

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Drastic reductions in Earth's biodiversity, old growth forests, top soil, clean water and air, and truly wild areas are occurring during a period when discussions of sustainable growth and sustainable production are becoming common. Using such terms as sustainable growth and sustainable production rather than the more accurate sustainable use of the planet leaves the impression that, with a little more skill, society can continue its present practices indefinitely. A number of explanations are possible for this desire to maintain two conflicting beliefs (i.e., severe environmental destruction occurs but society can continue its basic practices indefinitely): 1) the idea that a technological solution can be found for every problem; 2) an addiction to present behavioral norms, which is so strong that the consequences of continuing such behavior are irrelevant; and 3) the concept that, while human society can alter natural systems to suit its own needs, natural systems are incapable of altering human society. This last issue is the focus of this discussion: if human society eliminates all species on the planet that are incapable of tolerating human society's present practices, the only species remaining will be those that human society is unable to control successfully or eliminate; these species are called pests. Another hypothesis could be stated: a world of pests that human society cannot control effectively will inevitably reshape human society through disease and famine, technological breakdown, and interference with domesticated and wild species upon which the integrity of human societal structure depends. **Key words:** coevolution, discontinuities, endemic species, exotic species, human society modification, sustainability. *Environ Health Perspect* 104:1142–1145 (1996)

Cairns (1,2) and Cairns and Niederlehner (3) have made the case for the coevolution of human society and natural systems. Raven and Johnson (4) define coevolution as the simultaneous development of adaptations in two or more populations, species, or other categories that interact so closely that each is a strong selective force on the other. The effect of human society on natural systems is so well documented that to discuss it at length would be platitudinous. While many humans recognize that nature is irritating when encountered in the form of ticks, mosquitoes, poison ivy, and diarrhea-causing organisms, few people take seriously the proposition that human society can be dramatically altered by the selective forces inherent in natural systems. This discussion furnishes some examples of discontinuities caused by components of natural systems.

Can Natural Systems Affect Human Society?

The term discontinuity is used in this discussion to mean a break in continuity. In a sense, then, an activity of human society, such as the functioning of a steam electric power plant, may have its performance modified by invading exotic mussels. Most scientists and engineers and, arguably, the general public have no doubt that human society is having a major effect on natural

systems. However, the possibility that natural systems can have a major effect on human society is not generally accepted. Possibly, the idea of the weakness of natural systems surfaced when ecologists began referring to the fragility of ecosystems and global biotic impoverishment. Without question, coral reefs, tropical rain forests, and wetlands (only illustrative examples) are indeed fragile. The more mystical components of the environmental movement express reverence and respect for the interconnected web of life, giving the impression that if part of the web is damaged the damage will spread through all the connections and result in utter ruin. There are also many people who believe in the dominance of human society over nature—a view with considerable substance from the outset of the agricultural and subsequent industrial revolutions. All these elements easily lead to the view that human society is dominant and natural systems are submissive and, therefore, to be used as society chooses with relatively few consequences.

Another plausible view is that components of natural systems (i.e., many species) are tough and defy human management. Evidence shows that even following mass extinctions biodiversity was reestablished in geologic time, although not in the same form that it once was. Many species simply defy human society's

attempts to manage, control, and eradicate them. These pest species may compete with domesticated species for ecological resources and space and may also compete with humans directly for the solar energy converted into food stuffs and other usable material. Tough species affect human society in a number of ways, including epidemic diseases that affect either humans or domesticated animals and plants and disruption of technological systems. There are several difficulties in controlling exotic species, particularly in cases where the solution is known but the behavior of humans is difficult to change to resolve the problem.

A rather detailed case history on Lake Malawi illustrates 1) the conflict between short-term benefits for a specific group and long-term benefits for society as a whole; 2) that components of society (in this case, the fisherperson) may not accept a solution to a problem, even when the scientific evidence is strong; 3) that human society, or even the scientific community, may be unaware of the service until a thorough ecological study has been made; 4) that political systems are either unable to deal with the situation as a social problem or cannot find the finances to do so, even when the situation is dangerous to human health and evidence is persuasive; and 5) that basic research (in this case, on speciation of fish) often produces immediate short-term information; if the information is communicated, it may or may not lead to a solution of the problem. Following this rather extended case history is a series of shorter case histories, which are presented to illustrate the diversity of discontinuities.

Overfishing and the prevalence of schistosomiasis in Lake Malawi. It is hypothesized that snail-feeding haplochromine cichlid fishes in Lake Malawi (Africa) provide the important ecosystem service of limiting population densities of the snails that are intermediate hosts of schistosomiasis, a debilitating disease caused by blood-

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dwelling trematodes of the genus *Schistosoma*. An estimated 200 million people are presently affected by schistosomiasis, making it second only to malaria as the most prevalent parasitic disease on the planet (5,6). Schistosome trematodes can only complete their life cycles by infecting certain planorbid snail hosts (7). If present trends continue, overharvesting of snail-eating fishes may cause a major discontinuity in the schistosomiasis-controlling function of Lake Malawi.

Schistosomiasis has long plagued Malawi, but transmission of this disease was historically restricted to rice fields, slow-moving streams, and the swampy backwaters adjacent to the lake [(8–10); A.C. Evans, unpublished data]; the open waters of Lake Malawi were considered safe from schistosomiasis transmission (8). Lake Malawi contains some 28 snail species (11) of which 15 are endemic and more than 12 molluscivorous cichlid species (12) of which all are endemic. Two snail species are thought to act as the principal intermediate hosts of disease-causing schistosomes in Malawi: *Bulinus globosus* and *Biomphalaria pfeifferi* are hosts to the trematodes that cause urinary and intestinal schistosomiasis, respectively (8,13).

By conducting enclosure/exclosure experiments in Lake Malawi, McKaye et al. (12) confirmed that predation by four primary shallow-water molluscivores limits snail densities in open sand habitats of the lake; they found that, in laboratory experiments, these fishes prefer the thin-shelled intermediate host of schistosomiasis (*Bulinus globosus*) to the thicker-shelled nonhost species. Based on these findings, it was hypothesized that predation by snail-feeding cichlids prevents the intermediate snail hosts from entering the open waters of Lake Malawi, thus preventing the transmission of schistosomiasis in these areas (12). Subsequent experiments have demonstrated that one of the primary molluscivores, *Trematocranus placodon*, may be effectively used to control schistosomiasis hosts in aquaculture ponds in Malawi (14,15).

The fishes of Lake Malawi provide nearly 75% of the animal protein consumed in the country of Malawi (16,17). Snail-feeding cichlids are among those species that are consumed by the people of Malawi (J.R. Stauffer, personal communication). With a per capita gross national product of \$230 (U.S.), Malawi is one of the world's poorest nations and has the highest birth rate (54/1000) in the world (18). For these reasons and because of a decline in other employment opportunities, the number of Malawians turning to

fishing for their livelihood is rapidly increasing (17). Between 1988 and 1993, for example, the number of commercial trawlers operating in the southeast area, the most productive region of the lake, increased from 4 to 16, with adverse effects on fish diversity (19). Current fishing practices in Lake Malawi are far from sustainable, and appropriate regulations for the protection of fish production and diversity have yet to be implemented (16,17,19). Further studies are currently being conducted to confirm the disease-preventing role played by snail-feeding cichlids in Lake Malawi, to determine the degree to which snail-feeding cichlids may potentially limit the prevalence of schistosomiasis in Malawi, and to identify appropriate strategies for restoring populations of molluscivorous cichlids in Lake Malawi (J.R. Stauffer, personal communication).

In an earlier publication, Cairns (2) hypothesized that human society and natural systems are coevolving, that is, events in each shape events in the other. He also postulates two types of coevolution. One type is hostile coevolution in which human society makes little or no effort to preserve the integrity of natural systems and is left with those species (which are often labeled pests) that are most able to tolerate human activities. These are the species resistant to control measures and include agricultural pests, biofouling species, pathogens, disease vectors, and other undesirable organisms. A second type is benign coevolution in which human society alters its behavior to protect the integrity of natural systems and the services they provide. In the latter relationship, humans reciprocate by ensuring that the processes favorable to continuation of these services are not harmed or degraded; ecosystem services, such as the maintenance of the atmospheric gas balance or the regulation of diseases, benefit humans.

Although determining the strength of the link between overfishing and the prevalence of schistosomiasis in Lake Malawi awaits the results of current and future investigations, the postulated relationship serves as a useful heuristic tool. Given that the relationship is rigorously confirmed, the situation in Lake Malawi best fits the hostile coevolution definition. Benign coevolution would involve changing human behavior to either protect and maintain or enhance populations of the fishes that prey on snails carrying schistosomes.

By making relatively modest adjustments, it may be possible, and perhaps even probable, to maintain or restore a robust disease-controlling function in Lake Malawi if breeding stocks of indigenous snail-eating fishes can be enhanced. As

such, the impending discontinuity in Lake Malawi may be reversible, at least for some finite time period. Consider the sacrifices made by changing the behavior of human society that would be necessary to protect the fish that prey on snail hosts with the following public health options that might be either individually or collectively employed to prevent the spread of schistosomiasis: 1) the use of chemotherapy in humans to eliminate schistosome burdens; 2) the construction of latrines or other disposal units for human waste with concomitant provision of schistosome-free water for washing and bathing; 3) an increase in environmental literacy concerning schistosomes, particularly among children; and 4) the replacement of fish predation on snails by habitat modification (i.e., vegetation removal or draining schistosome source pools outside Lake Malawi) or the application of pesticides.

One might also contrast the expense to human society of reestablishing natural controls (which are cost free but do require some restraint to prevent overfishing or otherwise impacting populations of the fish species that are predators on snail hosts) with the cost of chemical controls, either in humans or in the environment. Regrettably, most environmental professionals would wager that the ecological solution, namely increasing the number of fish predators, is not likely to be attempted and, if attempted, is likely to be a compromise between fishing regulations and disease control. In either case, the behavior of humans will be dramatically altered. In the ecological alternative, voluntary modifications in behavior must be consistently followed, guided by scientifically generated information. If one or more of the technological solutions are chosen, society's behavior still must be altered so that these solutions are consistently used; however, technological strategies may clash with social customs. For example, even if safe washing facilities are constructed, rural African villagers often choose to continue washing their clothes at a traditional point in a stream or lake (where schistosomiasis transmission may occur) because of the social importance of daily gatherings at these sites (20).

Other examples. Garrett (21) notes a number of diseases that have become household words in the United States that were unknown just a few years ago. She hypothesizes that Lyme disease, which has serious effects on humans and is carried by indigenous, white-tailed deer (*Odocoileus virginianus*), is the result of the explosion of the deer population and the comingling of humans and deer. The deer population explosion is certainly the result of the elim-

ination of most of its natural predators (humans might be considered natural predators, but they are not particularly effective) and of ecological alterations that provide much habitat favorable to deer. Because both the human population and the deer population have been expanding simultaneously and are sharing overlapping ranges, the movement of the tiny ticks (*Ixodes scapularis*) that carry the disease from deer to humans is facilitated.

Garrett (21) discusses many other similar situations, e.g., the hanta virus in which humans and disease carriers are brought into closer proximity than they have been in the past. She also argues persuasively that human invasion of habitats once occupied primarily by other species or disruption of natural ecosystems in various ways (the white-tailed deer example is a good one) have caused disease discontinuities that were induced by human society. Of course, the best known of these is the resistance of many disease-causing organisms to antibiotics and other medicinal compounds (6).

In the United States, chestnut blight was caused by the deliberate introduction of the Chinese chestnut (*Castanea mollissima*) (22), which was more resistant to the disease than the American chestnut (*Castanea dentata*). This introduction resulted in major reductions in sizable specimens of the latter. A more recent publication (22) describes American chestnut blight, which is particularly heartrending in the Appalachian region of the United States. Chestnut blight first appeared at the Bronx Zoo (New York, NY) in 1904, perhaps accidentally introduced around 1890 with a nursery shipment of oriental chestnuts, which are more tolerant to the effects of the fungus; chestnut blight might also have arrived with a shipment of Chinese lumber (22). [See Weidensaul (22) for an interesting summary of discontinuities of this type in the Appalachians.]

While diseases have a greater emotional impact, other introduced species have taken an economic toll as a result of the discontinuities they have caused in both natural and technological systems. In an earlier paper, Cairns and Bidwell (23) reviewed technological discontinuities caused by the respective North American introductions of the Asian clam (*Corbicula fluminea*), the zebra mussel (*Dreissena polymorpha*), and the quagga mussel (*Dreissena bugensis*). The cost associated with the fouling of raw water intake systems and the ecological impacts of these pest species will run into the millions and possibly billions over the next decade.

Whereas the Asian clam and zebra mussel appear to have been introduced acciden-

tally into the United States in 1869, a number of egg clusters of the gypsy moth were brought from France to Medford, Massachusetts, by a French mathematician and astronomer who expected to develop a hardy, silk-producing insect by crossing gypsy moths with silkworm moths. Because some organisms escaped (24), it could be claimed that this was an accidental introduction; however, the fact remains that these organisms were transported across an oceanic barrier that they could not have surmounted themselves and, through carelessness, were released into an ecosystem where they expanded dramatically. By almost a century later (1949), the federal government and various states had already spent \$65 million attempting, with very limited success, to contain the gypsy moth (24). The amounts spent since then, and those that will be spent in the future, could have easily been saved had this organism not been introduced on the North American continent.

Strategies for Coping with Discontinuities

As a consequence of exotic colonization, each continent may be occupied by both exotics and indigenous species sharing two characteristics: resistance to diseases (one wonders if organisms can physiologically and genetically maintain countless resistances simultaneously; the fact that they do not do so now indicates the strong natural selection against resistances that are not often necessary for survival/reproduction) and the ability to coexist with human society and perhaps even thrive under these circumstances (although regional differences due to climate and other factors remain, undoubtedly such differences will be substantially reduced). It seems probable, therefore, that the near future will include continued reduction of the number of species on the planet. Natural forests and other ecosystems that harbor many species are disappearing at a rate unprecedented in human history while the demand for timber and other forest products is accelerating. Projected human population growth and increased levels of affluence, particularly in Asia, are likely to result in continued environmental destruction, which undoubtedly facilitates the establishment of exotics that are accidentally or deliberately introduced.

How this trend toward homogenization of the world's biota will affect travel and tourism is not yet clear, but surely it will diminish ecotourism if the biota looks much the same in similar climatic zones. Geoffrey H. Lipman, President of the World Travel and Tourism Council, states that

a clean, healthy environment is the core of the travel and tourism product, and envi-

ronmental quality—unlittered streets, clean seas and mountain slopes, smog-free air, and unpolluted rivers—is vital to the long-term success of the industry (25).

One quite predictable consequence is increased pressure on areas where indigenous species remain as a result of isolation (e.g., the Galapagos Islands) or effective environmental practices [e.g., restoration of Nonsuch Island in Bermuda as a living museum (26)]. Another highly predictable consequence will be the increased expenditure of time to cope with the new array of discontinuities. Multiple discontinuities will probably have a synergy that will accelerate the frequency and amplitude of all discontinuities. For example, an effort to control a discontinuity in a technological system (e.g., chlorine to control biofouling) may cause unwanted discontinuities in biotic processes, which synergistically interact with other anthropogenic perturbations. All of these situations might add feedback [examples of such synergistic feedback loops are given in Harte (27) and Lashof (28)]. The amount of energy and resources, including economic ones, necessary to cope with these discontinuities will be substantial. It is ironic that, had the same energy and resources been used earlier for good environmental management, many of these discontinuities would not have occurred or could have been better contained.

Discontinuities in natural systems may often be neither linear nor continuous. Harte (27) notes not only a positive side to synergy (linkages that render the whole greater than the sum of the parts) but a sinister side as well. The latter is due to the high probability of linkages among all deleterious changes in the environment (e.g., deforestation with concomitant loss of biodiversity, acid rain, stratospheric ozone depletion, loss of agricultural soils, toxics).

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